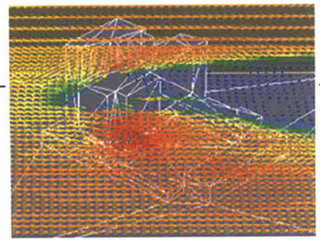
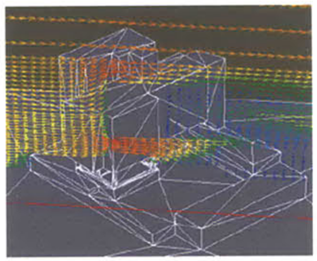
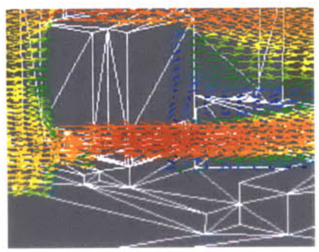






Building Community While Building Responsibly: A Sustainable Housing Complex for Central Los Angeles

by

Octavio Gutiérrez

Submitted to the Department of Architecture
in Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science in Art and Design at the
Massachusetts Institute of Technology

June 2001

Signature of Author: ______________________________
Department of Architecture
May 11, 2001

Certified by: ______________________________
John Fernandez
Assistant Professor of Building Technology
Thesis Supervisor

Accepted by: ______________________________
Stanford Anderson
Chair, Undergraduate Thesis Committee

A special “thanks” to my thesis supervisor, John Fernandez, Yi Jiang for her instruction in CFD, and the many MIT professors and teaching assistants who have provided the foundation for this work.

TABLE OF CONTENTS

INTRODUCTION

When the city of Los Angeles grew rapidly and relentlessly in the early to mid 20th century, many downtown homes were razed to make room for highways, office and civic buildings. Consequently, the downtown area lost its residential character and the area's more affluent residents fled to more desirable suburbs like Pasadena and West LA, leaving the central area to decay into a stereotypical inner-city slum. Today's mostly low-income minority residents live in crowded apartment units, give their public schools failing marks, and wallow through a sea of concrete and asphalt.

Shortage of open spaces, educational facilities, and housing units is a problem common to most growing big cities such as Los Angeles. Furthermore, these shortage crises often overshadow another equally important crisis: the environmental decay of the city. Buildings and cars pollute the environment, creating numerous health hazards for human life. Unfortunately, cities often sacrifice sustainable technologies for conventional designs that can be constructed quickly and inexpensively.

Rather than implementing a quick fix, dilapidated inner-city areas like Los Angeles's would better benefit from sustainable and affordable housing units and public outreach centers that build community and improve quality of life. In response to these needs, the proposed Sustainable Housing Project will place 40 affordable housing units, an educational outreach center, and a park on a Central Los Angeles site. The design will give careful attention to environmental responsibility and improving quality of life by following a set of sustainability priorities.

Downtown Los Angeles's Bunker Hill community in 1898. (Source: http://www.usc.edu/isd/archives/la/historic/AF1898.jpg)

SITE BACKGROUND

Location

Located about one mile north of Downtown Los Angeles, the triangular-shaped site selected measures roughly 65,000 square feet and slopes to the southeast. The site is bounded to the north by Bellevue Avenue, south by US Highway 101, east by Beaudry Ave and Sunset Blvd, and to the west by Victor Street. The highest elevation, 388 feet above sea level, is located at the corner of Bellevue and Victor, while the lowest point is 25 feet downhill near the intersection of Beaudry Ave and US 101.

Nearby land uses include high density residential (apartment buildings) directly across and further uphill along Bellevue Ave and small shops along Sunset Boulevard. There is also a motel, nightclub, and clinic at the corner of Sunset and Bellevue, as well as a shopping center anchored by a drug store at the corner of Sunset and Beaudry. Two public educational institutions—the Downtown Business Magnet School and the partially completed Belmont Learning Center—are south of the site along Beaudry Ave. Downtown Los Angeles's skyline is visible from most parts of the site, with the exception of those areas immediately adjacent the highway embankment.

Centrally located, the site is accessible by public transportation: a bus line that runs along Sunset Boulevard places Hollywood, Chinatown, Olvera Street, and Downtown Los Angeles within minutes.

Aerial and topographical views of the site.
(Source: http://www.topozone.com , USGS 5' contour map, w ith 1' lines interpolated)

Climate

Taking advantage of moderate year-round temperatures and constant wind directions to implement a natural ventilation system can greatly reduce heating and cooling loads, and Los Angeles has the ideal climate for such to happen. Winter temperatures average 60 °F, and winds from December to January blow mostly from the northeast. However, the remainder of the year is a comfortable 65 – 75 °F with breezes coming out of the west.

While Los Angeles is usually sunny, or at worst hazy in the morning until clearing in the early afternoon, it does receive about 12 inches of rain each year, with most of rain falling between November and April. However, El Niño events (which some speculate are occurring more frequently as a result of global warming) can bring heavy rains, overwhelming storm drainage systems and causing flash floods and excess soil saturation (which increases the danger of landslides).

View of site during the winter (December 2000)

Wind Data, 1930-1996

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Direction	NE	W	W	W	W	W	W	W	W	W	W	NE	W
Speed	7	7	7	7	6	6	5	5	5	6	6	7	6
Peak Gusts	49	40	47	40	39	32	21	24	27	48	42	44	49

Source: "Climatic Wind Data For The United States." Page 3. National Climatic Data Center, November 1998.

Temperature, Average Highs

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
58.3	60.1	60.7	63.3	66.1	69.9	74.3	75.1	73.7	69.7	63	58.3

Source: "Climatological Data Annual Summary," California 1999. Volume 103, Number 13. Page 20. US Department of Commerce.

DESIGN GOALS

The Central Los Angeles Sustainable Housing Project (CLASHP) is designed to bring together families and educational outreach services to a long-underserved area. By providing 40 units of affordable housing and classroom, computing, and meeting space, the CLASHP can begin to bring life back into a once-thriving area of Los Angeles.

Overall	
1. Housing	42,000sf
2. EOC	9,000sf
	51,000 NET SF
NSF/~0.73	**70,000 GROSS SF**
Detailed	
1. Housing:	
(10) 1-bedroom Units@850sf	8,500sf
(20) 2-bedroom Units@1000sf	20,000sf
(10) 3-bedroom Units@1250sf	12,500sf
Laundry, Office	1,000sf
	42,000 SF
2. EOC:	
(1) Community Meeting Space	2,500sf
(1) Library/Study Hall	2,500sf
(2) Classrooms @ 500sf	1,000sf
(4) Tutoring Rooms @ 250sf	1,000sf
(1) Computer Lab	500sf
(2) Offices @ 150sf	300sf
(2) Restrooms @ 100sf	200sf
Reception Area	500sf
Storage	500sf
	9,000 SF
Additional Space Considerations:	
Outdoor Public Space, such as a park	
(60) Parking Spaces – approx 16000sf:	
(1) space per 1-bedroomt	10 spaces
(1.5) spaces per 2-bedroom	30 spaces
(2) spaces per 3-bedroom	20 spaces
(10) Visitor Parking Spaces	

Program

The CLASHP consists of three distinct public elements: an educational outreach center (EOC), a park, and a residential building. The combined square footage of the residential building and EOC is about 70,000 square feet. Due to size constraints, a parking garage will be necessary to provide enough parking for the complex's residents, employees, and visitors.

The residential building will consist of approximately 10 one-bedroom, 20 two-bedroom, and 10 3-bedroom units, with a substantial amount of common outdoor space. A total of 60 parking spaces will be necessary for the residents. The EOC will have a public meeting hall and a library/study center in visible and accessible locations; classrooms, individual tutoring rooms, offices, the computer lab, and support spaces will also be included in the EOC, though need not be as visible. The EOC and residential building will be separated by public open space.

Sustainability Goals and Challenges

As a sustainable project, the CLASHP addresses the following goals:

1. Design for natural ventilation to assist in providing thermal comfort.
2. Achieve passive heating and cooling by maximizing and minimizing solar heat gains in the winter and summer, respectively.
3. Incorporate water and plants at various scales (from site to unit planning) to clean and cool air.
4. Control water runoff to alleviate load on drainage systems.

Goals 3 and 4 above can supplement each other and should not be difficult to achieve. Water runoff can be detained in a pool or basin; this water can then help cool ambient air and possibly be treated to help irrigate plants. More challenging though is designing for natural ventilation and passive thermal control: winds prevail out of the west, which is the same direction of the sun at its most intense (afternoon) hours.

Solution Method

In order to achieve the aforementioned sustainability goals, a schedule consisting of design and testing phases was established. The first design period, which produced a general massing of programmatic elements, was subsequently tested using computational fluid dynamic software to determine the ability to naturally ventilate. The second design period focused on mitigating solar heat gains through various screening devices; an energy analysis tested the performance of the building envelope. The last design phase incorporated the preceding design and testing phases to arrive at a final overall design.

DESIGN PHASE I:
Massing

Initial placement of elements was achieved through an examination of the surrounding land uses and the need to position the Educational Outreach Center in the most visible and easily accessible portion of the site. The resulting scheme thus layered the elements on the site from the most public to most private. The EOC was placed along Beaudry Avenue—an axis of existing public educational institutions— and was followed by public open space. The public open space, shielded from Beaudry Avenue traffic by the EOC and highway traffic by planting, is exposed to Bellevue Avenue and acts to soften the transition from fully public (EOC) to private (residential units). The residential building is then placed farthest from Beaudry and Sunset and closest to the residential zones further down Bellevue Avenue.

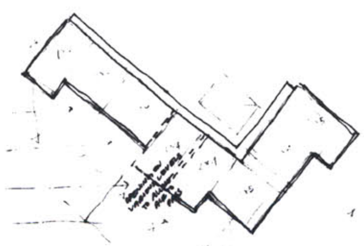
Top: View of apartments on Bellevue from Beaudry Avenue

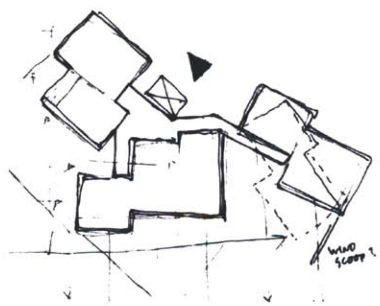
Middle: View of municipal building (left) and Belmont High School ballpark along Beaudry (right, under construction).

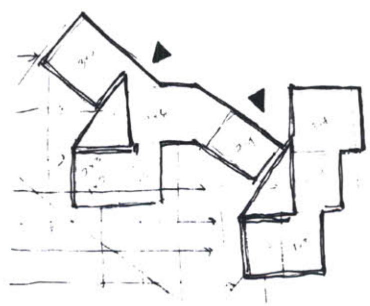
Bottom: View towards site from Downtown Business Magnet School also along Beaudry

Aerial View

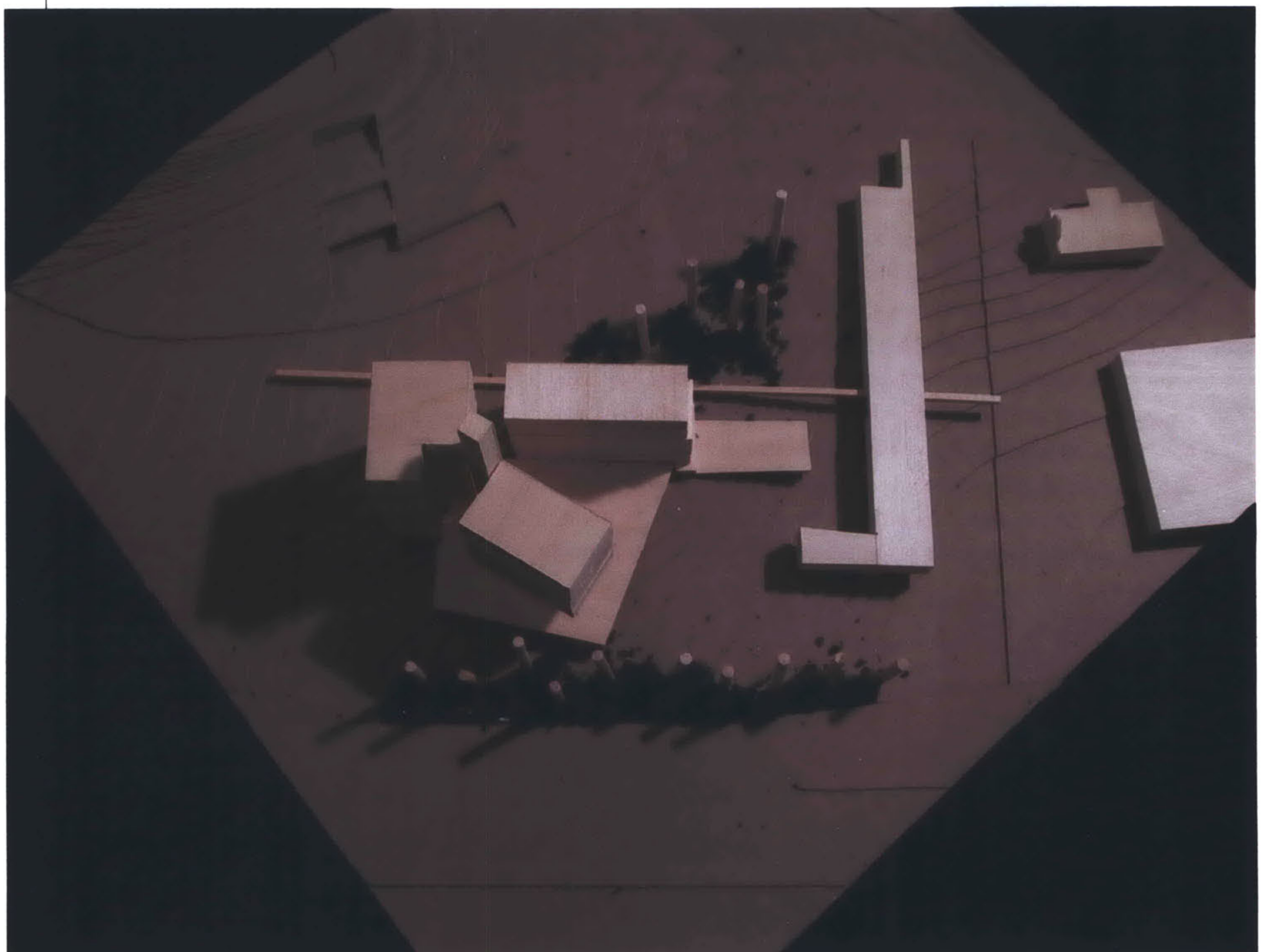
With the EOC and public open space in place, the massing exercises then concentrated on determining a general distribution and orientation of residential units that would aid in natural ventilation and the reduction of solar heat gains. However, the challenge of achieving these two sustainability goals through massing resulted in rather unconventional and undesired building forms. Stepped, low-rise, or multi-core building schemes required a larger footprint and began to encroach upon the public open space. Therefore, the scheme selected for testing exhibited a smaller footprint, 7-story single-core building with separation between three smaller towers. The core is open to the southwest and southeast while the building as whole faces southwest, which allows for some ventilation without entirely exposing the building to western solar radiation. A southwest orientation also creates a northeast "back" which can be more solid to prevent the colder winter winds from circulating through the core.







DESIGN PHASE I: Massing



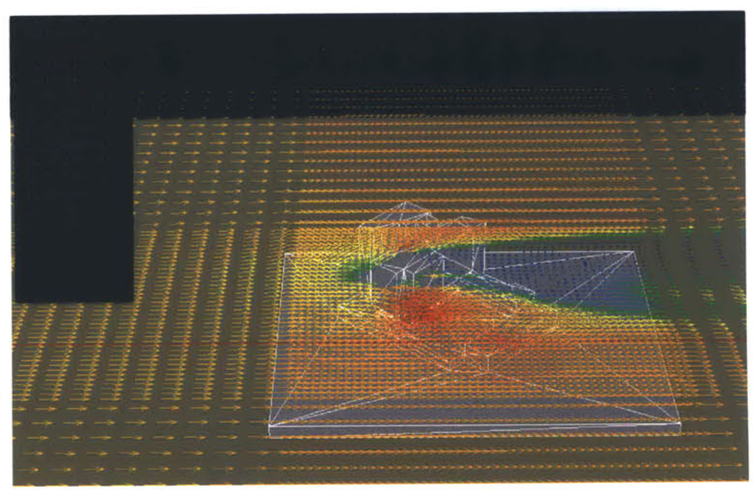
Overhead view of massing model.
Scale: 1"=32'-0"

TESTING PHASE I: Natural Ventilation

A three-dimensional computer model of the proposed scheme was created for testing with Phoenics, a computational fluid dynamics (CFD) software. The computer model consisted of simple boxes and did not take into account openings other than the open core. Therefore, the CFD study did not take into account airflow *through* the buildings but rather *around* them. The CFD study helped determine whether a pressure differential existed on opposite sides of the buildings, which is necessary for airflow. Individual residential units would then be designed to allow for proper air circulation through the unit.

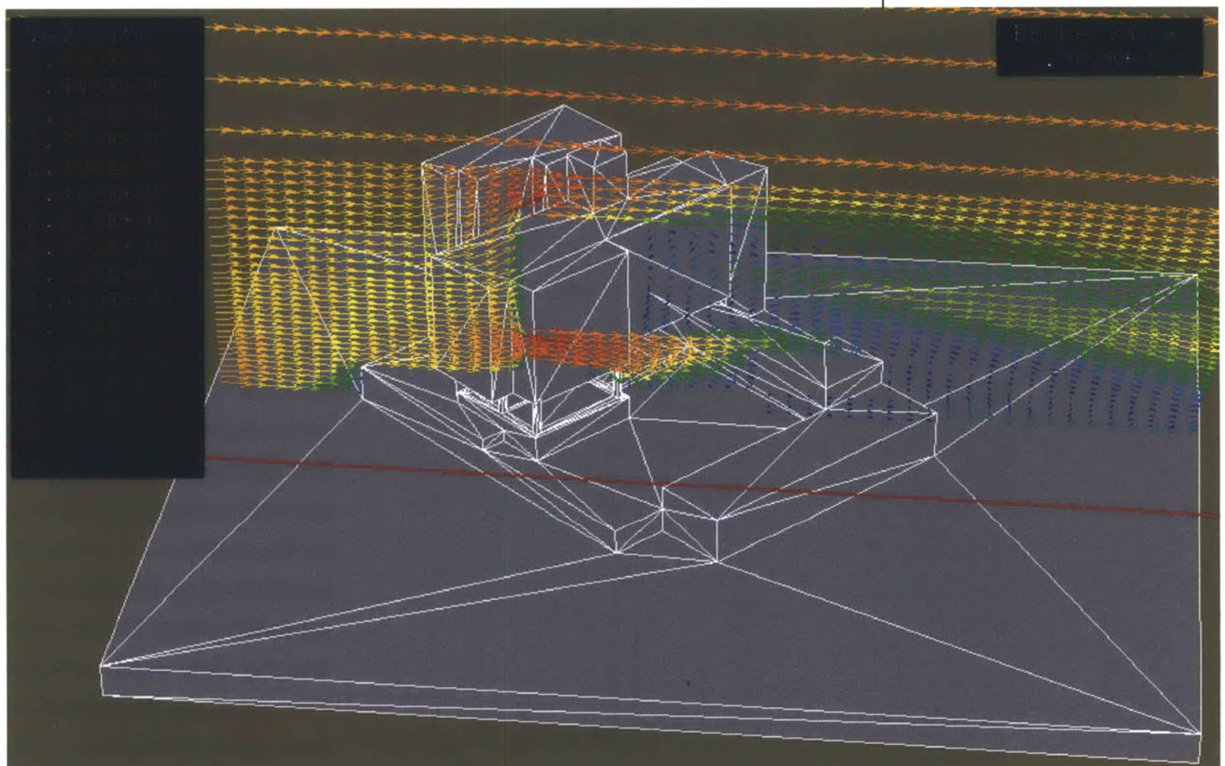
CFD

The computer model was tested under a 2.5 meter per second test wind prevailing from the west, and Phoenics provided predictable results: wind speeds around buildings, including through the separations, were accelerated as high as 3.7 m/s. On the other hand, the areas of low pressure behind the building exhibited decreased wind speeds as lo as 0.006 m/s.

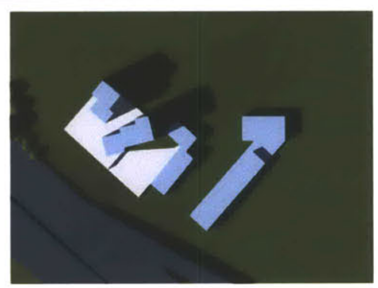


CFD test case, overhead view of complex. The warmer colors (orange to red) indicate accelerated wind speeds.

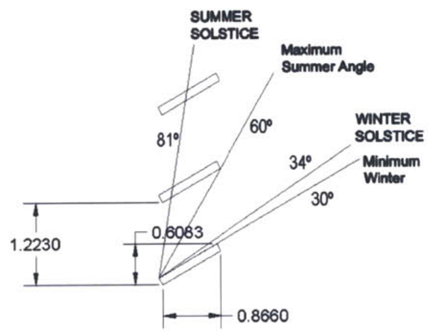
The Phoenics test case, while not the actual final massing model, did provide a general sense of how the winds affected the building for the given test conditions. In reality, wind is not constant in its westerly direction and may actually shift to a northwest or southwest direction. The test case was important in determining a magnitude of the winds, which when high can make an open space feel uncomfortable. CFD thus indicated that separation between buildings, while successful and imperative for natural ventilation, could also create wind tunnels that need to be addressed for safety and comfort. While the massing model was adjusted to solve geometric problems, the final model does not deviate greatly from the test configuration and thus accomplishes natural ventilation.

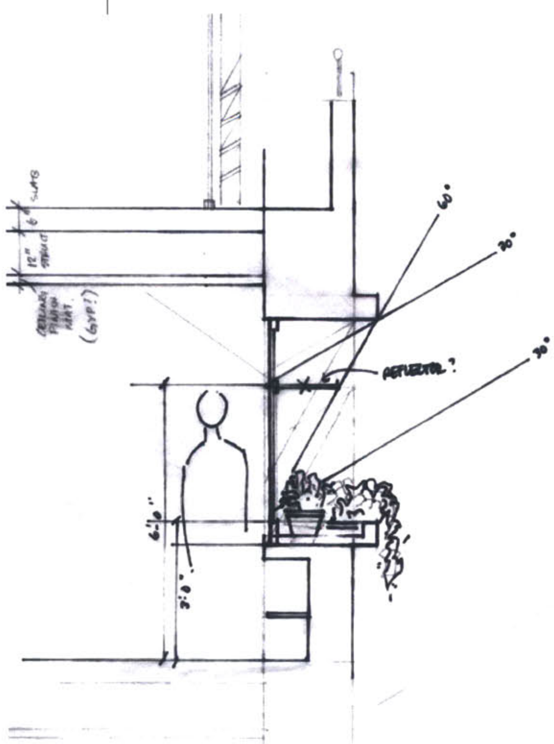


Above: CFD test case, overhead view showing sectional air flow. Note the decreased windspeeds/ lower pressure behind the buildngs.
Right: 3D massing model, early scheme



DESIGN PHASE II:
Solar Heat Gain Reduction





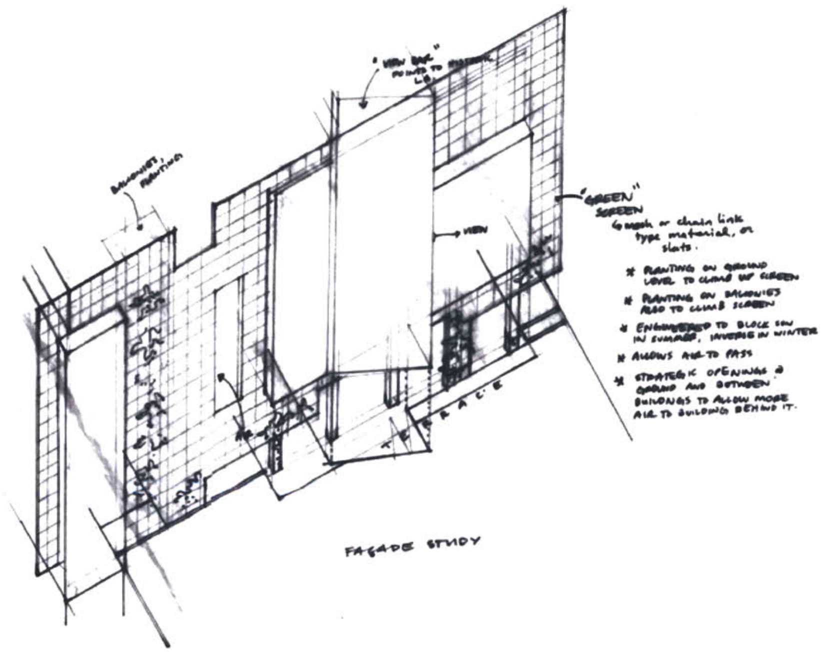
With a satisfactory ventilation scheme, the focus of design then shifted to alleviating the impact of solar heat gains. Data about sun's movement was useful in devising screen geometries that would reduce solar heat gains in the summer while allowing them in the winter.

Screens proposed for the southwest elevation (facing US 101) were designed to reduce mid-day to early afternoon solar radiation, during which sun's azimuth is mostly south to southwest. Two screening devices—recessed windows and aluminum slats over glass walls—were engineered achieve the desired goals. Slats were dimensioned and spaced to block all direct light at 60° and higher (10am-2pm at summer solstice) while blocking minimal light at 30° (10am-2pm at winter solstice). A successful vertical screen needs slats with cross sections of about 1½"x12", angled 30° from the horizontal, and repeated every 15"o.c. Recessed windows were similarly studied, and the ideal depth dimension for a 4'-0" high window was 2'-4". The ideal use for the extra-deep sill is a planter, since plants could help clean and reduce air temperature. If this dimension were still too deep, then a combination recessed window/canopy system could be implemented.

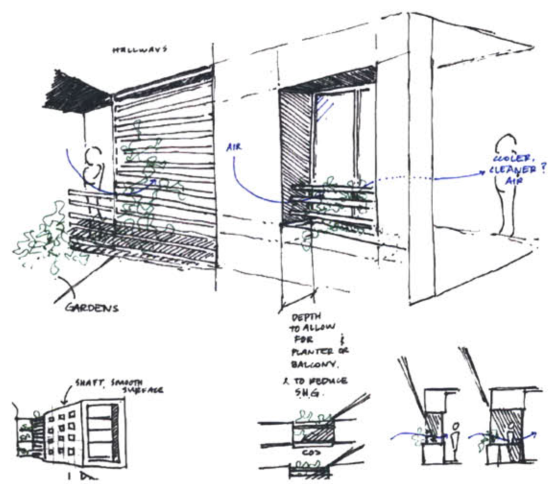
Top: Geometrical study of aluminum slats.

Bottom: Application of slat geometry to recessed windows.

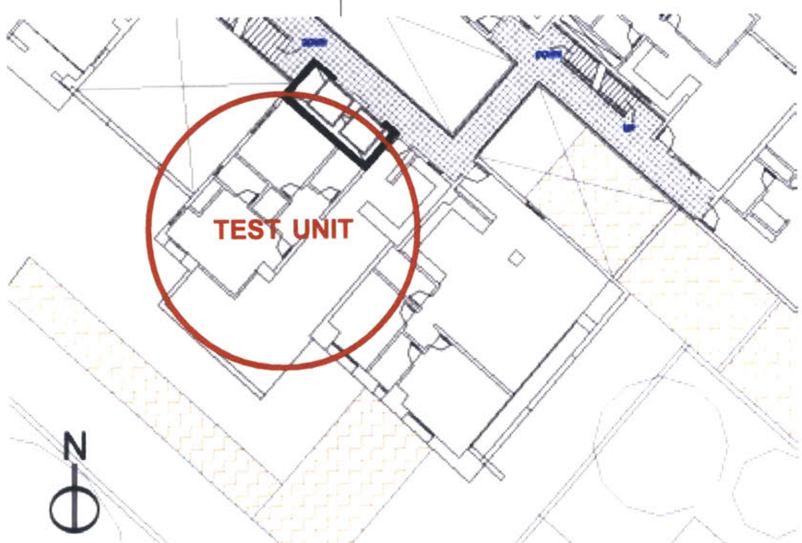
Since the slat screens and recessed windows perform similarly, there is a freedom to use either or both systems in any elevation. However, not all rooms in an apartment need (or should have) full-glazed walls; it is not practical to have a glass wall over a kitchen or bathroom. Furthermore, glass walls are *not* the most energy-conscious material as they have a high thermal conductivity (for a building material). The elevations should therefore utilize both systems, using recessed windows for more private rooms or where a glass wall is not practical, while using the slats over glass walls in living rooms, dining rooms, and perhaps one wall of a master bedroom.



A preliminary building envelope was designed using both recessed windows and aluminum slats. The US 101 elevation exhibited a combination of slats and recessed windows; the Beaudry Avenue elevation consisted stats and solid walls; the northeast (Bellevue Avenue) elevation was a combination of wall and glass (without screening devices, as that face of the building receives little direct sunlight); and the Victor Street elevation, which faces northwest, was give recessed windows. For testing purposes, it was assumed that either screen allows 75% of summer and 25% of winter light to pass.



TESTING PHASE II:
Energy Analysis



In order to assess the performance and thermal comfort of the residential units, an energy analysis was conducted for a south-facing two-bedroom unit during the month of June, the month during which most thermal discomfort in Los Angeles might occur. The unit selected had a total of about 300 ft^2 glazed and 1,000 ft^2 of stone-faced exterior wall. A list of typical apartment electronics and appliances and the time of day during which they are used (Appendix 1) was compiled to determine equipment loads. These loads were then added to solar heat gain loads and energy flows due to conduction/ convection/ radiation to arrive at a total energy load that was used to calculate the change in indoor temperature throughout the day.

To find the overall thermal conductivity of the stone and glazed walls, the conductive properties of each material were added to convection and radiation to arrive at an overall wall U-value. Indoor and outdoor radiation was assumed at 1 BTU/hr ft^2 °F; indoor convection at 1 and outdoor convection 3 BTU/hr ft^2 °F. The stone veneer's conductivity was assumed to be 0.5 (that of concrete); the conductivity of glass, insulation, and gypsum board are 0.5, 0.03 and 0.2. (*Source: "Heat Transfer," Table 1. Leon R. Glicksman, 1991, 1997*)

The U-value of a stone-faced wall section with 2" stone veneer, 10" insulation, and 1" of gypsum board was 0.034 BTU/ hr ft^2 °F, while that of a 1/4" glass pane was 1.27 BTU/ hr ft^2 °F. With these U-values, the rate of energy transfer between the interior and exterior of the unit, *q*, was calculated using the equation $q_{wall} = UA\ (T_{out} - T_{in})$.

With winter outdoor temperature values (T_{out}) of 60°F and indoor values (T_{in}) at 75° for, the rate of energy q_{wall} revealed a heat loss from the unit to the outdoors of 5.6 W/ft² (19.1 BTU/hr) through glass and 0.15 W/ft² (0.51 BTU/hr) through stone-faced walls. Summer outdoor temperature values (T_{out}) of 80°F and indoor values (T_{in}) at 70° yielded a heat gain of 3.7 W/ft² (12.7 BTU/hr) through glass and 0.10 W/ft² (0.34 BTU/hr) through stone-faced walls.

Added to the conductivity of the walls was the solar heat gain through the windows. Solar heat gain data for 34° N was found through *http://www.susdesign.com/windowheatgain/*, a JavaScript solar heat gain calculator. This online calculator takes into account solar heat gain coefficient for the window (0.79 for this case), window type (single-glazed aluminum frame) and ground reflectance (green grass, or 0.25), and then returns data for each month in the form of average watt-hours/m² per day. The data was then converted to Watts and multiplied by the screen coverage factor to arrive at a total solar heat gain. This data, along with calculations for thermal conductivity, are presented in Appendices 2 and 3.

The average rate of heat transfer for the month of June accounts for equipment loads, solar heat gains, and wall conductivity. The morning and evening energy usage peaks reflect the greater use of electronics and appliances; the drop in the load in the middle of the day represents reduced activity in the apartment unit.

Solar Heat Gains
2 Bedroom Test Unit

$Q_{Solar\ Gains}$ Through Windows, 34°N
(Data Source: http://www.susdesign.com/windowheatgain/)

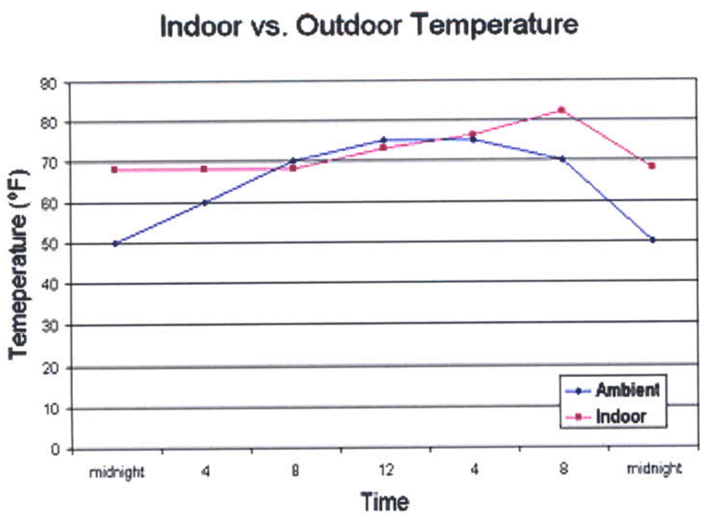
	June
WEST WINDOWS Jan - Dec W-hr/m², Daily	2007
Daylight Hours/Day	15
Hourly Average (W/m²)	134
Watts/ft²	12
SOUTH WINDOWS	893
Hours/Day	15
Hourly Average	60
Watts/ft²	6
Screen Coverage of **75%** (Summer Approx.) and 25% (Winter Approx.)	June
Modified SHG - West	**3.11**
South	**1.38**
Daily SHG Average [(W+S)/2] in W/ft²	2.25
SHG, total for 300 ft² of glazing, in Watts	**674**
Energy Transfer due to Convection, Conduction, Radiation, through windows in W/ft² *	3.7
Total, for 300 ft² of glazing, in Watts	**1110**
Energy Transfer due to Convection, Conduction, Radiation, through walls in W/ft² *	0.10
Total, for 1,000 ft² of walls, in Watts	**100**
TOTAL HEAT TRANSFER, in Watts	**1884**

See Appendix 3 for other months

TESTING PHASE II: Energy Analysis

Total Heat Transfer (June):

	Equipment	Cond/SHG	Total (q)
8am-Noon	1947W	2000 W	**~4000 W**
Noon-4pm	573 W	2000 W	**~2500 W**
4pm-8pm	2425 W	2000 W	**~4500 W**



See Appendix 4 for detailed calculations.

Load totals were next used to determine the change in temperature within the test unit. Treating the air and slab as single system in equilibrium simplified the task of tracking temperature changes throughout the day. ΔT was found through the heat transfer equation $Q=\Sigma\ mc\Delta T$, where Q is the total energy in watts (Joules/second) and *mc* is the product of a material's mass and specific heat capacity. The initial apartment temperature (8am) was assumed the same as ambient temperature, or 68°F (20°C), and according to the calculations described above, the temperature in the unit had risen to 73.2°F by noon, 76.4°F by 4pm, and 82.2°F by 8pm. These calculations are detailed in Appendix 4.

Conclusions

The screening devices played an important role in keeping indoor temperatures close to outdoor ambient temperature. Although the overall energy analysis of a test unit shows that temperatures reach uncomfortable levels by late afternoon, a cooling system could provide the necessary relief. An ideal cooling system would be a radiant slab, where chilled water is circulated through concrete slabs. Water can be circulated as temperatures indoor rise above a certain tolerable limit (75°F), and the system could be part of a geothermal cooling scheme that would greatly reduce energy consumption.

Equally important in any passive design is to educate the users, or residents in the case of the apartments, about what they can and should do as their share of responsibility. Night cooling will be necessary to bring morning temperatures down and keep daytime temperatures to a minimum. And in general, the residential units should be kept well ventilated whenever summertime ambient outdoor temperature is lower than indoor temperature.

DESIGN PHASE III: Final Design

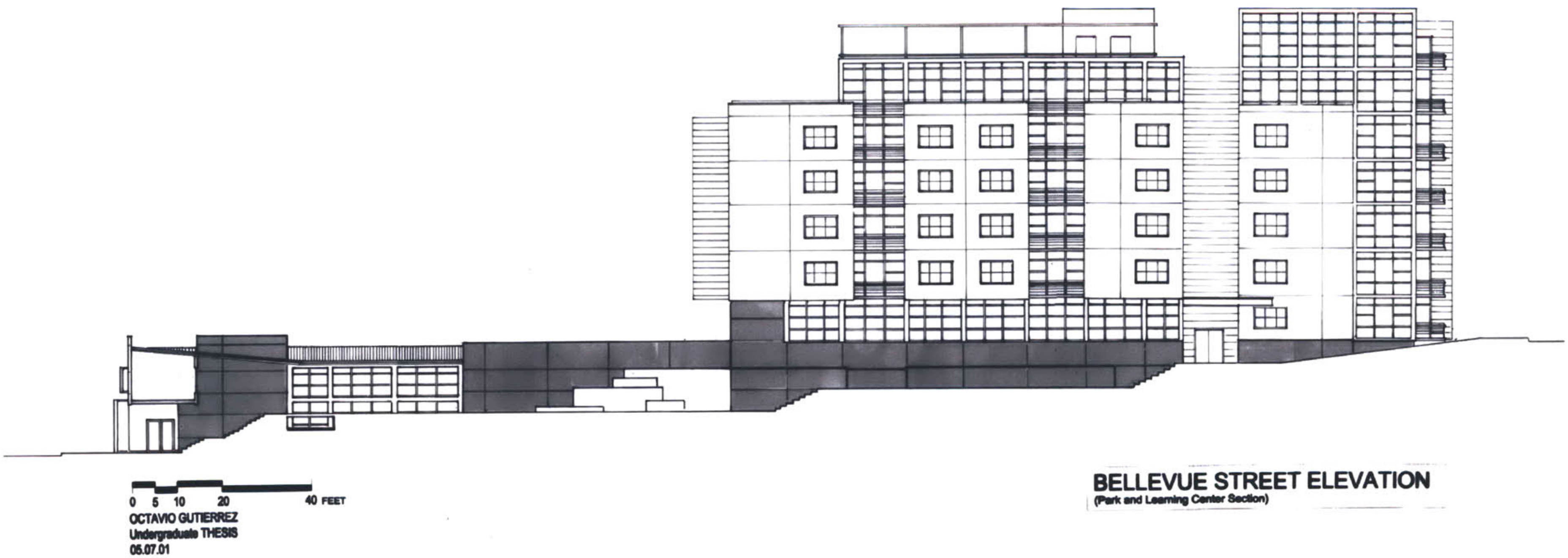
In summary, the final design of the Central Los Angeles Sustainable Project incorporates the conclusions of the two design and testing phases as follows:

1. The residential building consists of three separated blocks. Separation aides air circulation through the buildings by creating localized pressure differentials. CFD testing confirms the separation's satisfactory performance.

2. Screening devices in the form of aluminum slats and deep windows help shade undesirable summer solar radiation. Energy analyses showed only slightly intolerable levels of internal heat gains, which could be rectified by a radiant slab cooling system.

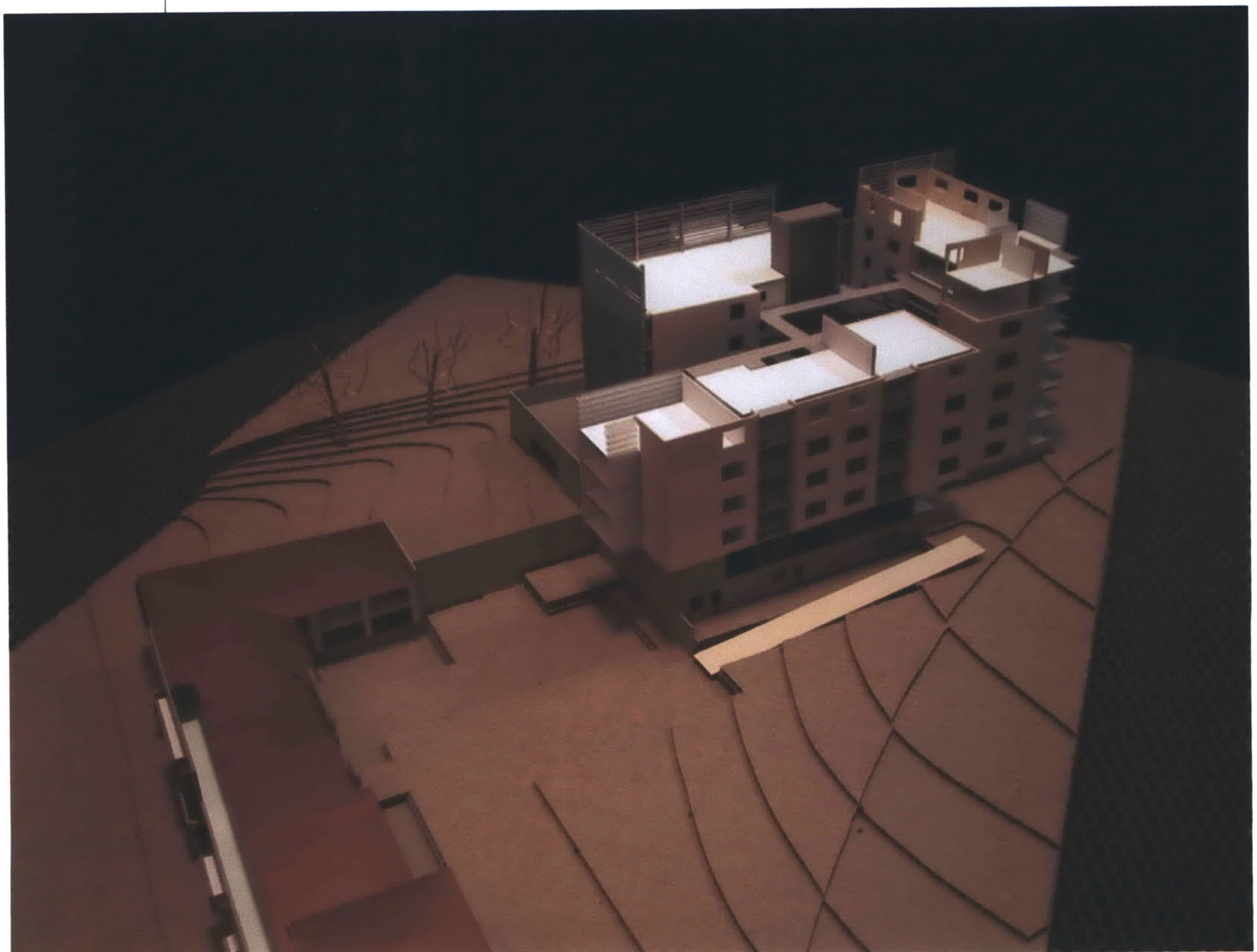
The sustainability goals of runoff control and planting were achieved through site planning which took advantage of the site's slope. A detention basin is included near the base of the site, close to the study hall of the Educational Outreach Center. There are generous plants planned to create a buffer between the complex and the major highway. Street trees are standard around the site, as are trees in the park between the EOC and residential building. This site planning scheme of water and plants should help cool air while creating a more inviting and comfortable space for the entire community to use.

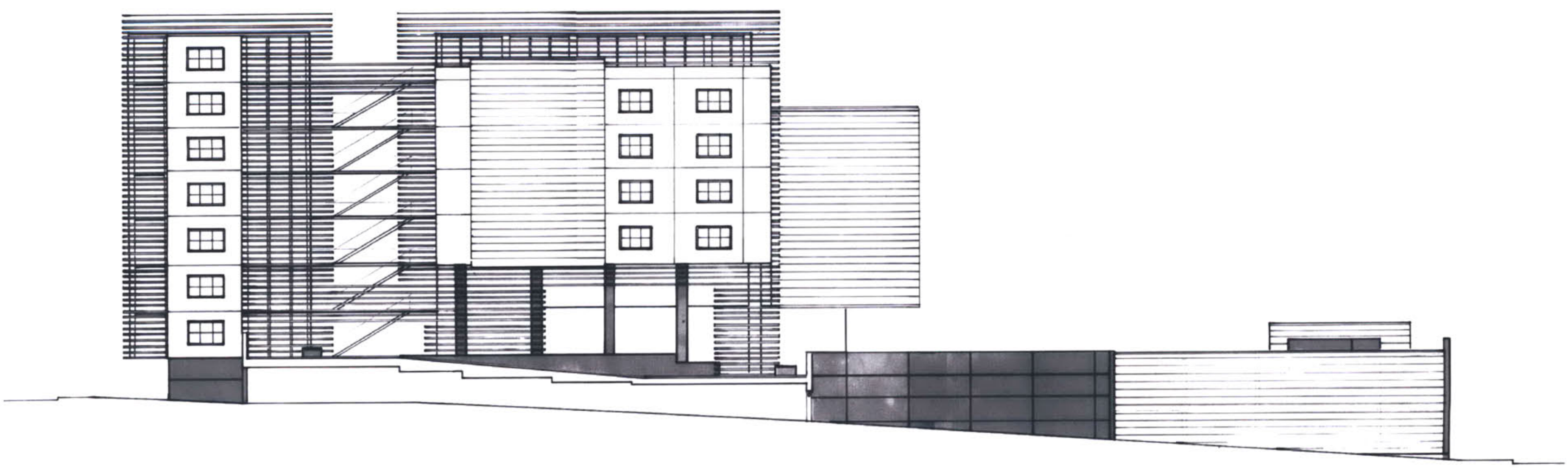
With a sustainability framework in place, the final design process followed a more traditional design exercise in detailing the layout of individual units. A short exercise in computer modeling yielded visualizations of the interior of a three bedroom unit. Those renderings, along with plans, elevations, and photos of a physical model are presented in the following pages.



BELLEVUE STREET ELEVATION
(Park and Learning Center Section)

DESIGN PHASE III:
Final Design

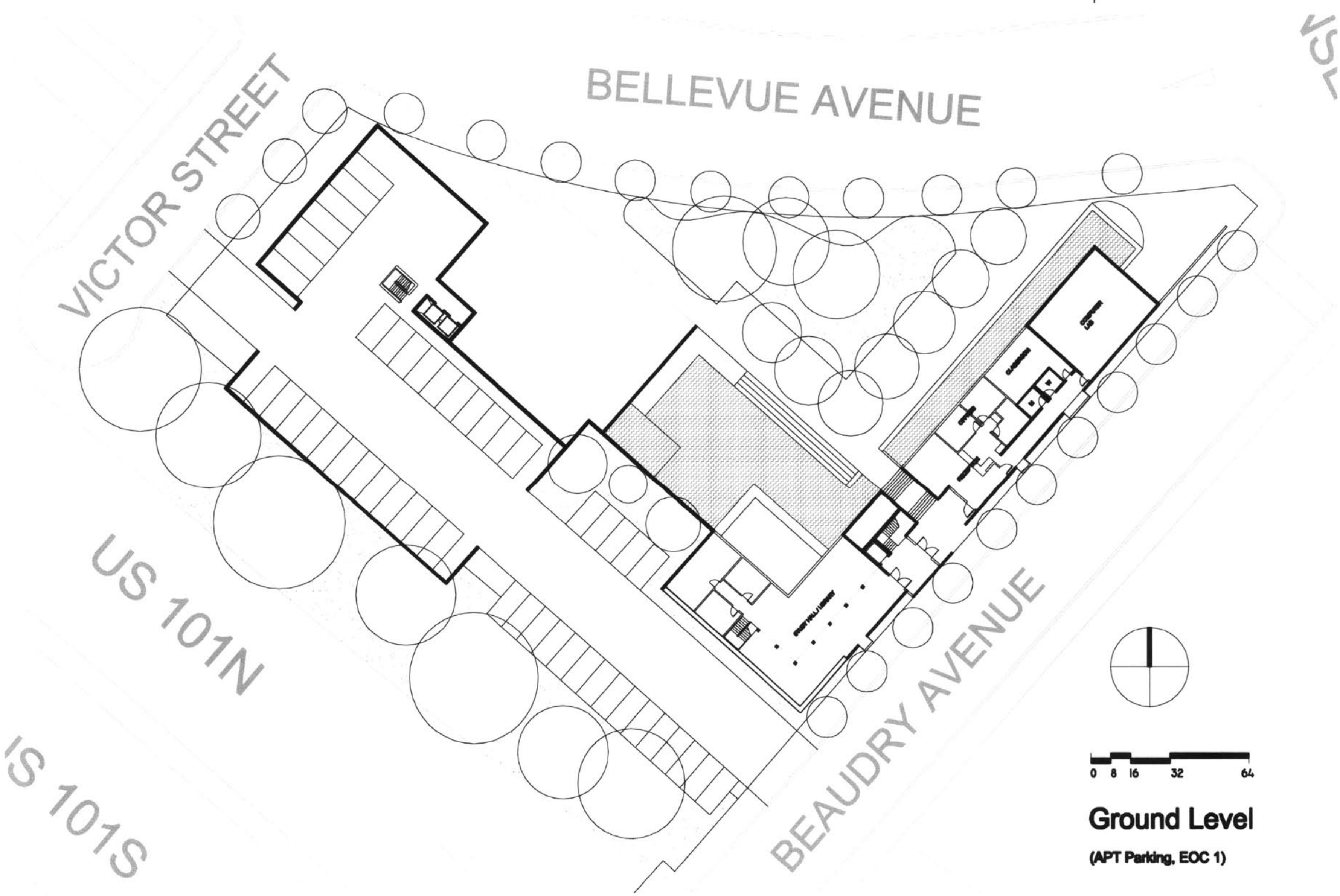




0 5 10 20 40 FEET
OCTAVIO GUTIERREZ
Undergraduate THESIS
05.07.01

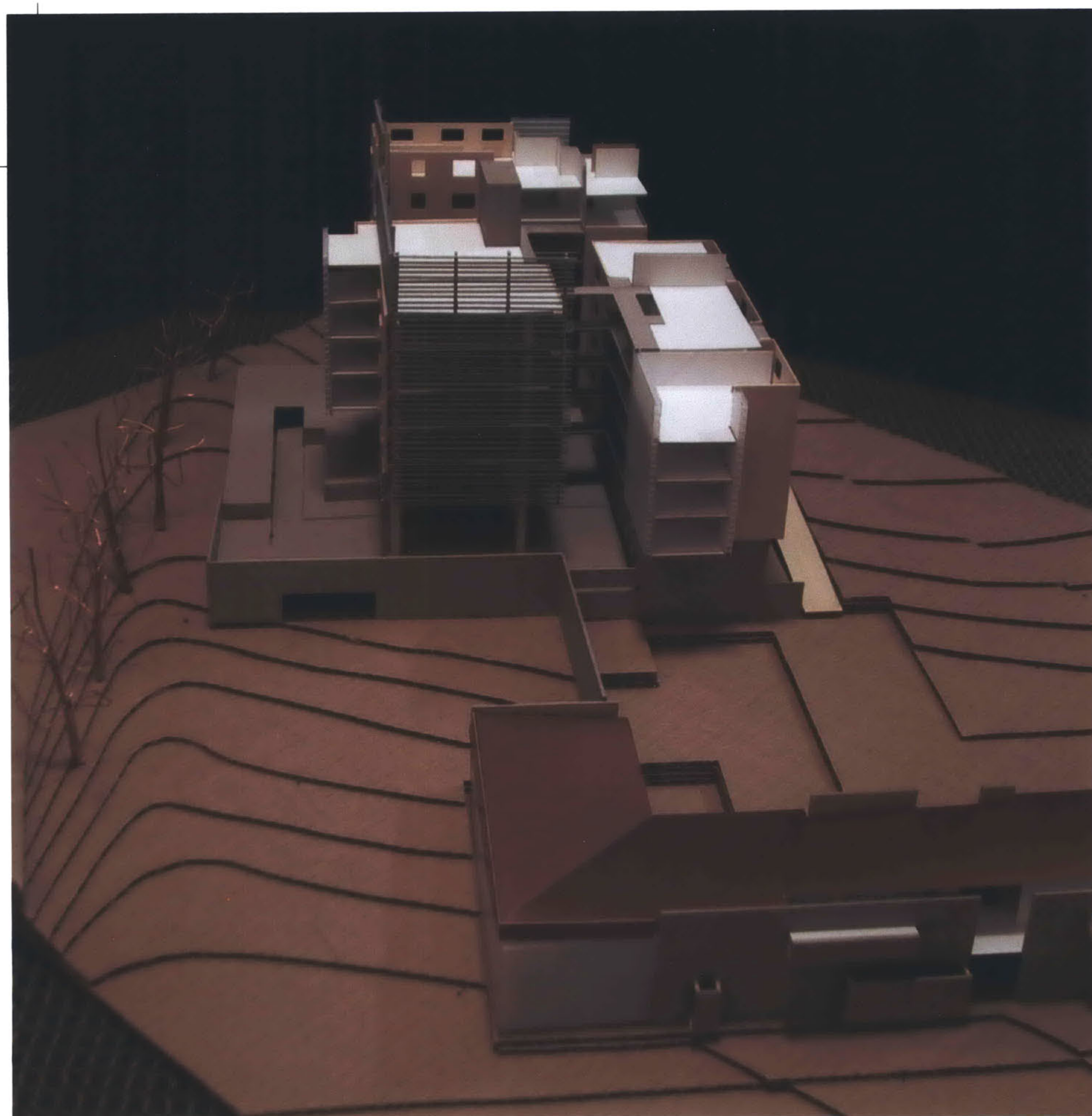
U.S. 101 ELEVATION
(Parking Structure Section)

DESIGN PHASE III:
Final Design

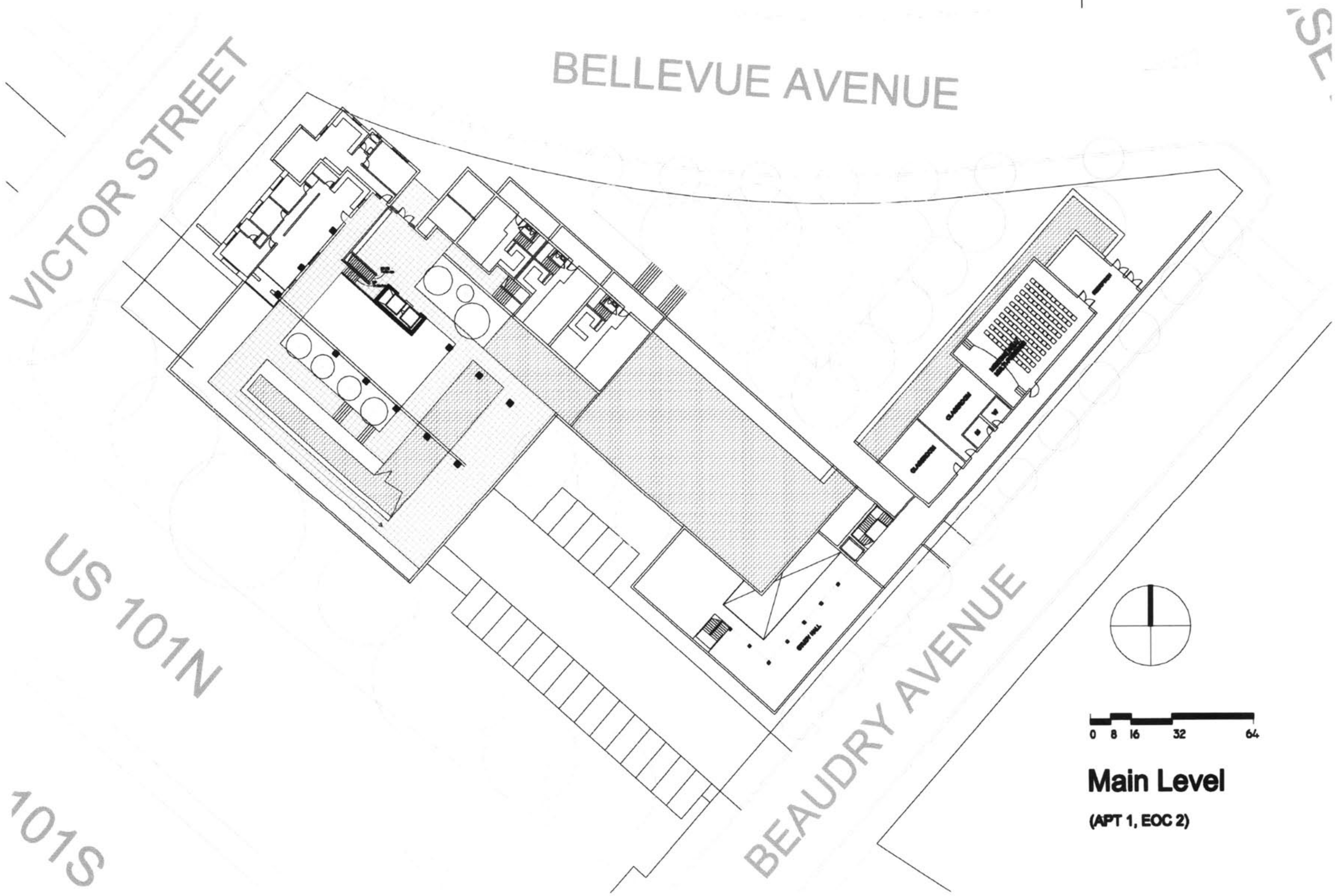


Ground Level

(APT Parking, EOC 1)

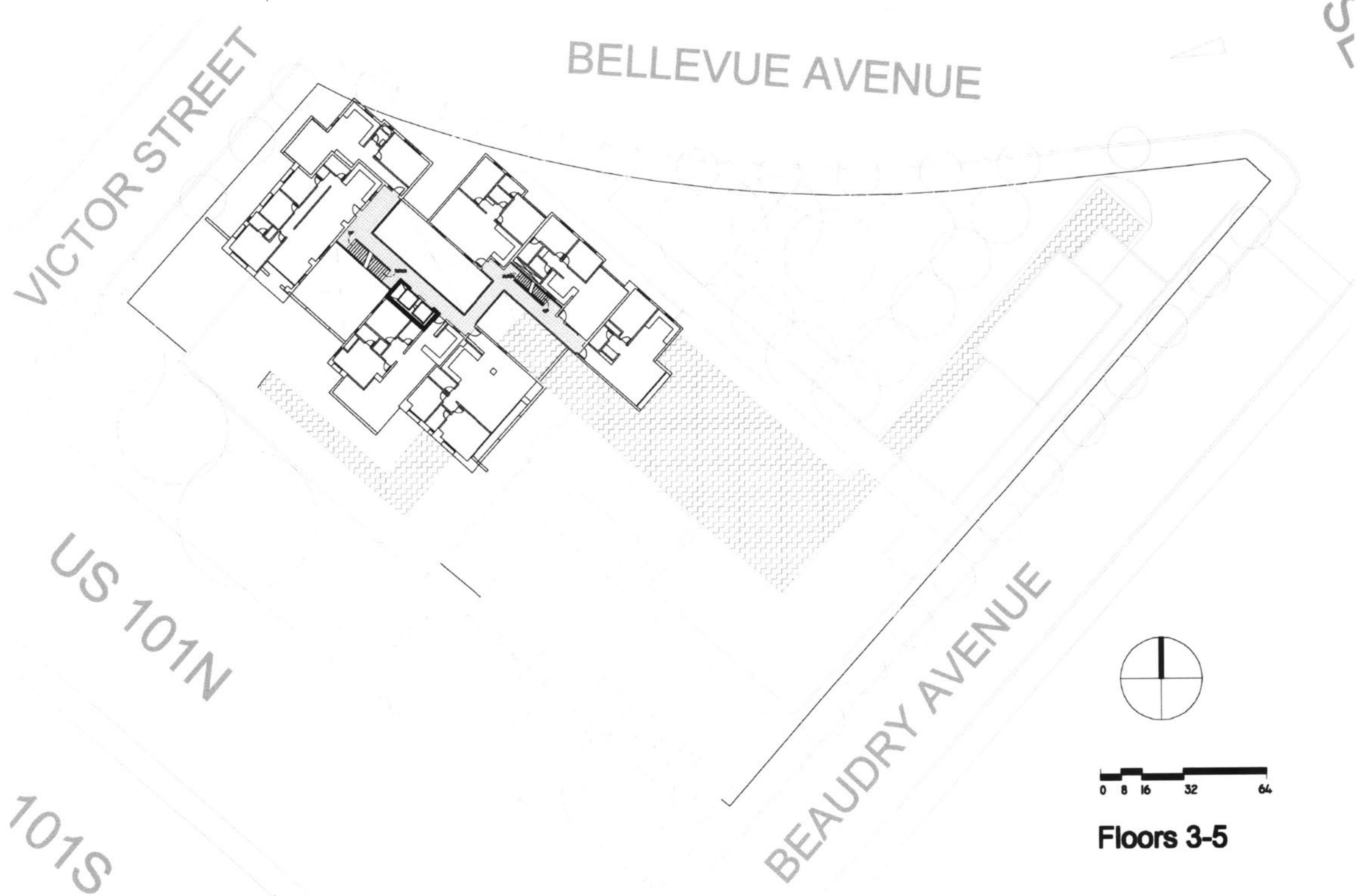


DESIGN PHASE III:
Final Design



Main Level

(APT 1, EOC 2)


BELLEVUE AVENUE
VICTOR STREET
US 101N
101S
BEAUDRY AVENUE
0 8 16 32 64

Floors 3-5

DESIGN PHASE III:
Final Design

3-Bedroom Floor Plan (Detail) and
computer model looking in from balcony

Close up of 3-bedroom units

Appendix 1

Equipment Loads

Equipment	8a-12p	12p-4p	4p-8p	Rating
Electrical Lighting - Room Lights, 4x75 W	150	0	600	300
Electrical Lighting - Other Lamps, 2x75 W	75	0	150	150
Full-Size Refrigerator	400	400	400	400
Microwave Oven (Compact)	113	0	113	900
Coffee Maker	113	0	0	900
Toaster	313	0	0	1250
Iron	275	0	0	1100
Hair Dryer	156	0	0	1250
Blender	50	0	50	400
TV-25"	50	100	100	100
TV-19"	0	0	70	70
VCR	0	0	0	30
Computer	125	0	250	250
Computer Monitor	45	0	360	90
Laser Printer	10	0	40	40
People	73	73	292	73
Total Watts, all Equipment	1947	573	2425	

Appendix 2

Thermal Conductivity Calculations

Stone-faced wall

$U_{stone\ wall} = 1 / [1/(h_{rad}+h_{conv})_{out} + L/k_{stone} + L/k_{insulation} + L/k_{gypsum} + 1/(h_{rad} + h_{conv})_{in}]$

where $h_{rad,out} = h_{rad,in} = 1$

$h_{conv,out} = 3$ and $h_{conv,in} = 1$

L = thickness in feet, $L_{stone} = 2"$; $L_{insulation} = 10"$; $L_{gypsum} = 1"$

k = conductivity, $k_{stone} = 0.5$; $k_{insulation} = 0.03$; $k_{gypsum} = 0.2$

$$\begin{aligned} U_{stone\ wall} &= 1 / [1/(1+3) + (2/12)/0.5 + (10/12)/0.03 + (1/12)/0.2 + 1/(1+1)] \\ &= 1 / [0.25 + 0.33 + 27.78 + 0.42 + 0.5] \\ &= 1 / 29.28 \\ &= 0.034 \text{ BTU/hr ft}^2\ {}^{o}\text{F} \end{aligned}$$

$$\begin{aligned} q_{stone\ wall,\ winter} &= (T_{out} - T_{in})(\text{Area of Wall})(U_{wall}) \\ &= (60\ {}^{o}\text{F} - 75\ {}^{o}\text{F})(\text{Area of Wall})(0.034 \text{ BTU/hr ft}^2\ {}^{o}\text{F}) \\ &= -0.51 \text{ BTU/hr ft}^2 \qquad (1 \text{ watt} = 3.4 \text{ BTU/hr}) \\ &= -0.15 \text{ watts/ft}^2 \end{aligned}$$

$$\begin{aligned} q_{stone\ wall,\ summer} &= (T_{out} - T_{in})(\text{Area of Wall})(U_{wall}) \\ &= (80\ {}^{o}\text{F} - 70\ {}^{o}\text{F})(\text{Area of Wall})(0.034 \text{ BTU/hr ft}^2\ {}^{o}\text{F}) \\ &= 0.34 \text{ BTU/hr ft}^2 \qquad (1 \text{ watt} = 3.4 \text{ BTU/hr}) \\ &= 0.10 \text{ watts/ft}^2 \end{aligned}$$

For all stone walls: (1,000 ft²) (–0.15 watts/ft²) = **–150** watts in the winter
(1,000 ft²) (0.10 watts/ft²) = **100** watts in the summer

Appendix 2 (Continued)

Glazed wall or window

$U_{window} = 1 / [1/(h_{rad}+h_{conv})_{out} + L/k_{window} + 1/(h_{rad} + h_{conv})_{in}]$

where $h_{rad,out} = h_{rad,in} = 1$

$h_{conv,out} = 3$ and $h_{conv,in} = 1$

L = thickness in feet, $L_{glass} = 0.25"$

k = conductivity, $k_{glass} = 0.5$

$$
\begin{aligned}
U_{stone\ wall} &= 1 / [1/(1+3) + (0.25/12)/0.5 + 1/(1+1)] \\
&= 1 / [0.25 + 0.042 + 0.5] \\
&= 1 / 0.79 \\
&= 1.27 \text{ BTU/hr ft}^2\ {}^\circ\text{F}
\end{aligned}
$$

$$
\begin{aligned}
Q_{window,\ winter} &= (T_{out} - T_{in})(\text{Area of Window})(U_{window}) \\
&= (60\ {}^\circ\text{F} - 75\ {}^\circ\text{F})(\text{Area of Window})(1.27 \text{ BTU/hr ft}^2\ {}^\circ\text{F}) \\
&= -19.1 \text{ BTU/hr ft}^2 \qquad (1 \text{ watt} = 3.4 \text{ BTU/hr}) \\
&= -5.6 \text{ watts/ft}^2
\end{aligned}
$$

$$
\begin{aligned}
Q_{window,\ summer} &= (T_{out} - T_{in})(\text{Area of Window})(U_{window}) \\
&= (80\ {}^\circ\text{F} - 70\ {}^\circ\text{F})(\text{Area of Window})(1.27 \text{ BTU/hr ft}^2\ {}^\circ\text{F}) \\
&= 12.7 \text{ BTU/hr ft}^2 \qquad (1 \text{ watt} = 3.4 \text{ BTU/hr}) \\
&= 3.7 \text{ watts/ft}^2
\end{aligned}
$$

For all glazing: ($300\ ft^2$) ($-5.6\ watts/ft^2$) = **–1680** watts in the winter
($300\ ft^2$) ($3.7\ watts/ft^2$) = **1110** watts in the summer

APPENDIX 3: Solar Heat Gains

$Q_{\text{Solar Gains}}$ Through Windows, 34°N

(Data Source: http://www.susdesign.com/windowheatgain/)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
WEST WINDOWS Jan - Dec W-hr/m², Daily	1098	1510	1869	2014	2011	2007	2476	2344	1945	1489	1164	981
Daylight Hours/Day	9	11	11	13	15	15	15	13	11	11	9	9
Hourly Average (W/m²)	122	137	170	155	134	134	165	180	177	135	129	109
Watts/ft²	11	13	16	14	12	12	15	17	16	13	12	10
SOUTH WINDOWS	2940	2894	2313	1453	999	893	1231	1682	2437	2831	3094	2981
Hours/Day	9	11	11	13	15	15	15	13	11	11	9	9
Hourly Average	327	263	210	112	67	60	82	129	222	257	344	331
Watts/ft²	30	24	20	10	6	6	8	12	21	24	32	31

Screen Coverage of **75%** (Summer Approx.) and 25% (Winter Approx.)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Modified SHG - West	8.50	9.57	**3.95**	**3.60**	**3.11**	**3.11**	**3.84**	**4.19**	**4.11**	**3.15**	9.01	7.60
South	22.77	18.34	**4.89**	**2.60**	**1.55**	**1.38**	**1.91**	**3.01**	**5.15**	**5.98**	23.96	23.09
Daily SHG Average [(W+S)/2] in W/ft²	15.64	13.95	4.42	3.10	2.33	2.25	2.87	3.60	4.63	4.56	16.49	15.34
SHG, total for 300 ft² of glazing, in Watts	**4691**	**4186**	**1325**	**929**	**699**	**674**	**861**	**1079**	**1388**	**1369**	**4947**	**4603**
Energy Transfer due to Convection, Conduction, Radiation, through windows in W/ft² *	-5.6	-5.6	0	0	3.7	3.7	3.7	3.7	3.7	3.7	0	-5.6
Total, for 300 ft² of glazing, in Watts	**-1680**	**-1680**	**0**	**0**	**1110**	**1110**	**1110**	**1110**	**1110**	**1110**	**0**	**-1680**
Energy Transfer due to Convection, Conduction, Radiation, through walls in W/ft² *	-0.15	-0.15	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.00	-0.15
Total, for 1,000 ft² of walls, in Watts	**-150**	**-150**	**0**	**0**	**100**	**100**	**100**	**100**	**100**	**100**	**0**	**-150**
TOTAL HEAT TRANSFER, in Watts	**2861**	**2356**	**1325**	**929**	**1909**	**1884**	**2071**	**2289**	**2598**	**2579**	**4947**	**2773**

* For March, April, November, $T_{in}=T_{out}$

Appendix 4

Total Heat Transfer (June):

	Equipment	Cond/SHG	Total (q)
8am-Noon	1947W	2000 W	**~4000 W**
Noon-4pm	573 W	2000 W	**~2500 W**
4pm-8pm	2425 W	2000 W	**~4500 W**

Change In Temperature over Time

$q = \sum mc\,\Delta T$ mass, $m = \rho V$

density, ρ, $\rho_{concrete}$ = 2,400 kg/m³; ρ_{air} = 1.21 kg/m³

specific heat, $c_{concrete}$ = 880 J/kg °C; c_{air} = 700 J/kg °C

Volume of air in test unit: 10,000 ft³ or 283 m³
Volume of 4" concrete slab: (1,000 ft²)(4"/12") = 333 ft³ or 9.42 m³

From 8am-Noon:

ΔT = q / [(1.21 kg/m³)(283m³)(700 J/kg °C) + (2,400 kg/m³)(9.42 m³)(880 J/kg °C)]
= (4,000 W) / [(239,701 J/ °C) + (19,895,040 J/ °C)]
= (4,000 J/s) / [20,134,741 J/ °C]
= 0.00019866 °C/s (1hr = 3600 s)
= **0.72 °C/hr**

From Noon-4pm:

ΔT = q / [(1.21 kg/m³)(283m³)(700 J/kg °C) + (2,400 kg/m³)(9.42 m³)(880 J/kg °C)]
= (2,500 W) / [(239,701 J/ °C) + (19,895,040 J/ °C)]
= (2,500 J/s) / [20,134,741 J/ °C]
= 0.0001242 °C/s
= **0.45 °C/hr**

From 4pm-8pm:

ΔT = q / [(1.21 kg/m³)(283m³)(700 J/kg °C) + (2,400 kg/m³)(9.42 m³)(880 J/kg °C)]
= (4,500 W) / [(239,701 J/ °C) + (19,895,040 J/ °C)]
= (4,500 J/s) / [20,134,741 J/ °C]
= 0.0002235 °C/s (1hr = 3600 s)
= **0.80 °C/hr**